CHAPTER 11

RELAYS AND CONTROLS

Section I-RELAYS, ELECTRIC POWER APPARATUS

11-1. Relay functions.

A relay is an electric device designed to interpret input data in a prescribed manner. When specific input conditions occur, the relay responds to cause contact operation or a similar sudden change in associated electric control circuits.

a. Electric power apparatus relays. This section describes electric power apparatus relays and relay systems which are designed to operate circuit breakers and contactors, usually medium-voltage units. Relays can be set more precisely than fuses. Relays are adjustable with respect to both time and current, a feature that also applies to solid-state, direct-tripping, low-voltage circuit breakers.

b. Input data. Input data analyzed is usually electrical, but may be mechanical or thermal, or evaluate other conditions or a combination of conditions. Electrical conditions can be overcurrent, overvoltage or under-voltage, a combination of current and voltage, current balance, direction of current flow, frequency, impedance, or other electrical data.

c. Industrial control relays. Relays of the type designed primarily for industrial control, for switching of communication or other low-level signals, or for any other equipment not controlling electric power apparatus are described in the CONTROLS section of this chapter.

11-2. Relay fundamentals.

Electric power apparatus relays operate to quickly sense problems and speedily isolate power systems under fault conditions. Such an action limits the extent of electrical equipment damage and provides a means to limit outage periods. Their definition, classification, and functional use in electrical power systems are defined by industry standards, prepared and coordinated by IEEE. Maintenance personnel should be familiar with these standards. IEEE also provides recommended selection and application practices, which are used by engineers designing military facilities.

a. Classification: Relays can be classified by functions, input operating principals, and performance characteristics. ANSI/IEEE C37.90 covers classifications of relays and also standard service conditions, ratings, tests, and temperature rise.

(1) *Functions.* Relays are classified according to their primary purposes, which are protective, regulating, monitoring, programming, and auxiliary control. Some relays may qualify for more than one classification, depending on their application.

(2) *Inputs.* This classification has to do with the input to which the relay responds such as current or voltage.

(3) *Operating principles.* This classification identifies the relay's operating principles or structural features, such as electromechanical or solid-state types.

(4) *Performance characteristics.* Relays are selected to perform certain functions. To standardize on reference use, they are given device function numbers by IEEE C37.2. (Device function numbers also describe other electrical power apparatus equipment in addition to relays.) Device function numbers readily identify devices in drawings, diagrams, instruction books, publications and specifications. The use of "52" for circuit breakers, "51" for an ac time overcurrent relay, "65" for a governor, and "86" for a lockout relay provides a simple brief method of designation of the device's operational performance. The standard also covers suffix letters used for main devices (such as "N" for neutral), actuating qualities (such as "A" for amperes), auxiliary devices (such as "CS" for control service), operating device components (such as "TC" for trip coil), and auxiliary contact positions (such as "a" and "b", "aa" and "bb"). Familiarity with this standard, including typical elementary diagrams, will help in understanding device operations.

11-3. Relay construction.

All relays operate in response to one or more electrical or physical quantities to open or close contacts or trigger power electronic devices, such as thyristors. Relays will generally be of the electromechanical or solid-state type.

a. Electromechanical relays. These relays have been used for years and provide simplicity, reliability, security, low-maintenance, and long life. Basic units are constructed to respond instantaneously or with a time-delay to the actuating quantity.

(1) *Instantaneous units.* Instantaneous units act on an electromagnetic attraction operating principle wherein a plunger, solenoid, hinged armature, or balance-beam is pulled into a coil or pole face of an electromagnet. They can be used in both ac and dc power systems.

(2) *Time-delay units.* Time-delay units act on an electromagnetic induction operating principle, whereby torque is developed in a movable rotor (disc or cup) which rotates between two faces of an electromagnet. These units can only be used in ac circuits. Time overcurrent and time under/overvoltage relays are generally of the disc design type, while high-speed overcurrent, directional, differential, and distance relays are more often of the cup (cylinder) design type.

b. Solid-state relays. Solid-state relays are extremely fast in their operation, as they have no moving parts. Other advantages are lower burden, high seismic-withstand, and reduced panel space. Many are programmable, allowing increased choices of time-current characteristics.

c. Usage. There are no formal statistics available, but one manufacturer estimates that 40 to 50 percent of their relays sold in 1992 were solid-state units. By the year 2000, this manufacturer estimates that of their total relay sales 85 to 95 percent will be the solid-state type. Solid-state relays require no preventive maintenance, but they do require a periodic maintenance check.

11-4. Relay maintenance periods.

Frequency of maintenance should be such as to reveal any possibilities of failure. Maintenance records will disclose trends which might lead to such failures.

a. Test considerations. Tests should simulate normal operating conditions. Avoid overtesting because such tests can often cause more problems than they correct. Consider the variables that can cause problems, such as relay complexity, environment, history, and facility relay-type experience. Other considerations are relay age and relay stress (relays operated at greater currents and/or control voltages because of station expansions).

b. Frequency. Inspections made every 2 to 3 years is usually sufficient. Testing may be necessary after a relay operation. Visual inspections of the target should be made any time other area visual inspections are required. Relay settings should be checked at least once a year and after any incorrect operation or redesign of the system. These inspections, supplemented by suitable tests, should be thorough enough to detect any faulty relays, settings, or wiring errors before trouble is encountered.

11-5. Relay general field inspection.

Relays should be completely disconnected from any live circuit when they are inspected or tested. Only specially trained electricians should be permitted to repair and adjust relays. The manufacturer's instructions should be checked for the proper procedures. Major repairs and testing should be conducted in a facility's testing laboratory, or by contract personnel with access to any special testing equipment needed.

a. Electromechanical relays. Check contacts, moving parts, connections, and the case and covers of these relays.

(1) *Contacts.* Contacts must be kept clean. A flexible burnishing tool should be used for cleaning silver contacts. Silver contacts should not be cleaned with knives, files, abrasive paper or cloth, as these items may leave scratches which can increase arcing and hasten deterioration of the contacts. Abrasive paper or cloth may, in addition, leave minute particles or insulating abrasive material in the contacts, and thus prevent closing. Contact wipe and resistance are important in all relays and should be checked as part of the maintenance procedure. Contact resistance can be determined by using an ohmmeter. Where this resistance depends on springs, the contact pressure should be checked using a spring gage. High resistance of such contacts may indicate insufficient spring pressure, which will require replacement of the spring. The relay must be deenergized and disconnected when the contacts are tested.

(2) *Moving parts.* It is important that all moving parts operate smoothly, so keep all bearings, shafts, linkages, and other moving parts free and clear of dirt *or* gum. Relays normally require oiling only when replacing a jewel, shaft, or moving part. Too much lubrication of these parts can lead to serious troubles and should be avoided. The relay disks should be cleaned with a thin brass or bronze magnet cleaner having a steel edge or insert. Relays should be quiet when operating. A noisy relay should be checked for loose parts or excessive play, and corrective measures should be taken.

(3) *Connections.* Relay connections should be thoroughly checked as part of the maintenance inspection. Check all screws and nuts for tightness. Check the relays, and as much of the circuitry as possible, for continuity, grounds, and shorts.

(4) *Case and cover.* To prevent dirt from entering the case, ensure there is a tight seal between the relay cover and its gasket. Any dust or dirt within the case should be brushed, blown, or vacuumed out. Care should be taken that dirt is not blown deeper into the relay necessitating removal and overhaul of the relay.

b. Solid-state relays. Many solid-state relays have easy-to-use built-in operational test diagnostics. Calibration tests are made in the conventional manner. Maintenance is generally not required, in the usual sense of adjusting, cleaning, or lubricating. Check external connections. It may be necessary to disassemble the relay. It is very important to follow the manufacturer's printed procedures. Replacement parts are available, but their use is not recommended. Printed circuit boards are easily damaged. Direct replacement does not necessarily mean the relay will operate properly, without further calibration or verification. When more than inspection and operating checks are necessary, it is recommended that the relay be returned to the manufacturer.

11-6. Relay performance tests.

These tests are usually provided for equipment acceptance, but may be necessary if the relay is completely replaced.

a. Operational checks. Before returning a relay to service, test the complete wiring installation for continuity and operate the relay contacts, preferably by test current, to ensure that everything is in order for the intended function. Any changes in the relay calibration, or needed adjustments should be made at this time. Normally adjustments in the relay settings will not be necessary, but proof checks must be made. Manufacturers' instruction books should also be checked to determine the proper procedure and test equipment required for specific relays. In some cases, the relay may have to be removed and inspected in a laboratory.

b. Directional test. Where directional relays are used, an overall test should be made to ensure that they operate in the proper direction.

c. Dielectric test. When dielectric or insulation tests are made, they should be performed on the complete installation or on all the component parts. For relays rated up to 6000 volts, the test should be made at twice rated voltage plus 1000 volts (with a minimum of 1500 volts ac for one minute).

d. Calibration and performance tests. Some of the tests that are run on the more common relays are shown herein. In addition, the manufacturer's instruction book should be checked for proper testing procedure of a specific relay. The time between tests will be determined by installation conditions and changes in the system. Regularly scheduled tests should be supplemented by special tests, made at any time protective equipment damage is suspected and while protected equipment is out of service.

11-7. Common electromechanical relay tests.

Always follow the manufacturer's instruction manual for tests and checks. The following information provides generalized test connections for the most common type relays used on military installations. Actual test connections may be more complex.

a. Overcurrent relays. Overcurrent relays are the relays most often used. They provide either primary line protection, or backup protection when more complex relays are used for primary protection to provide additional reliability.

(1) *Nondirectional units.* Nondirectional overcurrent relays should be tested at several points on the timecurrent curve, allowing suitable intervals between tests for cooling. Measure the reset time and minimum operating current. Check instantaneous element for pickup and contact action at high and low currents. Caution should be exercised so as not to "burn up" the relay when testing on high currents, or continuously testing at lower currents. Test connections for overcurrent relays are shown in figure 11-l.

(2) *Directional overcurrent relay.* Check the overcurrent element in the same manner as for a nondirectional overcurrent relay. Before testing the overcurrent element, verify the operation of the directional element by simulated fault currents and voltages. Check the minimum operating current of the overcurrent element at normal voltage, and check the contact gap spacing of the directional element. For typical test connections, see figure 11-2.

b. Differential relays. Figure 11-3 shows a typical test connection for a percentage differential type. Check the minimum operating values at zero restraining current and the operating points at several values of restraint. The slope (differential characteristic) and, where applicable, the harmonic restraint feature should also be checked. It may be desirable to trip all circuit breakers from differential relays as a regular testing procedure.

c. Distance relays. Check currents and phase angles, angle of maximum torque, and directional characteristics. Test operating sequences, including time, contact resistances, and relay reach, at various load power factors and settings. Figure 11-4

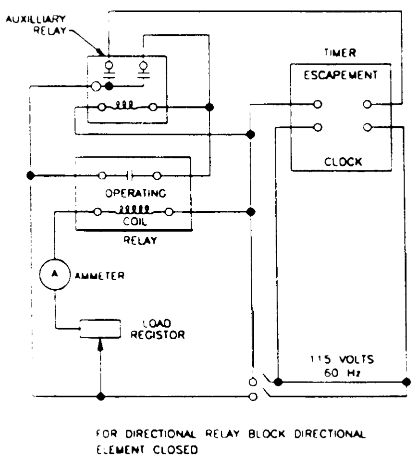

Figure 11-l. Typical test connection for a nondirectional overcurrent relay

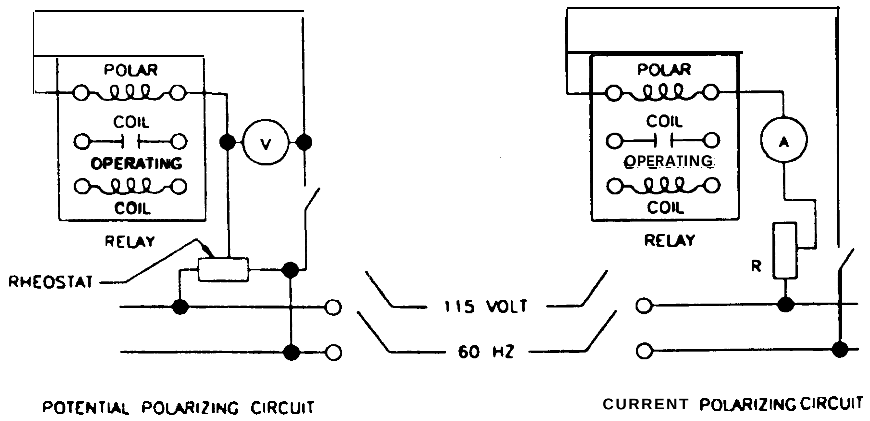

Figure 11-2. Typical test connections for directional overcurrent relays

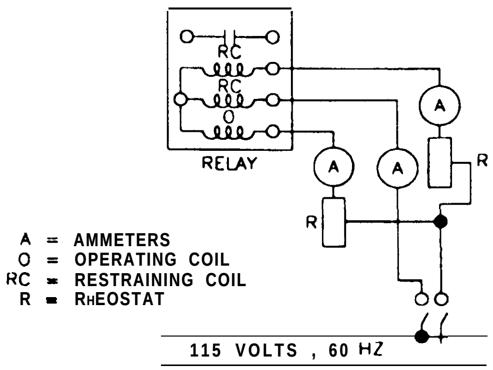

Figure 113. Typical test connections for a differential relay

shows a typical test connection for reactance relays. Substitute a resistor for the reactor when checking the polarity of impedance distance relays.

d. Pilot wire relays. Test the relay for minimum pickup, operating time, and restraint torque. Check the circuits for continuity and reversed connections. An overall test should be made to check the complete installation, including the pilot circuits and external devices associated with the installation. For test connections, see figure 11-5.

e. Synchronism check relays. Check the timing, polarity, and phase angle (closing).

f. Reclosing relays. Check the complete timing and reclosing sequence. Test initial and delayed reclosures and observe switches and moving parts.

g. Plunger and hinged armature relays. Check the relay pickup and drop-out values by gradually increasing or decreasing the operating current or voltage.

h. Thermal relays. Test for thermal pickup current with the relay hot and check the pickup of the instantaneous unit.

11-8. Relay test equipment.

Before testing minimize potential trouble by advance preparation.

a. Advance field testing preparation. Study system protection, including station single lines and relay instruction books. Obtain and review previous tests and arrange to have all required test equipment. Check that outage requests, switching arrangements, and any remote operations have been scheduled.

b. Field test equipment. The test equipment for field testing must be portable, so tests can be made at the relay panel. For most of the common relays, the following will be needed: a variable voltage autotransformer, a multirange ac and dc voltmeter, a multirange ac and dc ammeter, an ohmmeter, auxiliary current transformers, a timer, a three-phase shifter, and auxiliary relays. Test plugs, leads, noninductive resistors, and a relay tool kit will also be required. In general, most laboratory test equipment is portable and can be used in the field. Test instruments are available in prepackaged test sets. The use of these sets simplifies testing.

c. Laboratory testing. If the field testing indicates that a relay needs a shop repair, then engineering evaluation is necessary in determining what effect its removal will have on the reliability of the protective system. Short time removals of one phase of three-phase protective items, switching to alternate power sources, or a replacement relay with correct settings may be necessary. Such judgment should be made as a part of the advance field testing preparation.

d. Laboratory test equipment. Some of the common test equipment that should be available in a laboratory for servicing relays is shown in table 11-l. In addition to these devices, a relay tool kit, test plugs, test leads, printed circuit board extenders, a frequency generator, ac and dc power supplies, a portable test unit, an oscillograph, a power amplifier, and special equipment testers, as required for certain types of relays, will be needed. When selecting types and outputs of test equipment, consideration should be given to the various

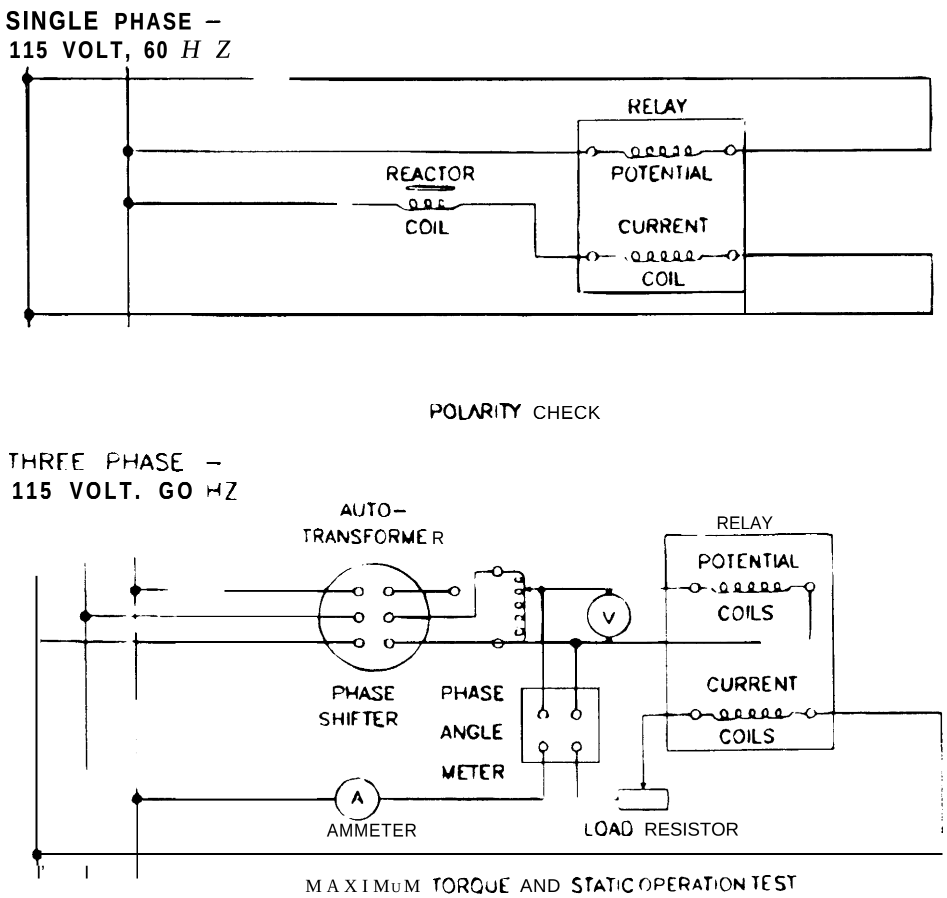

Figure 11-4. Typical test connections for reactance distance relays

types and operating requirements of the relays and associated equipment to be tested in a particular facility.

11-9. Relay repairs.

Relay repairs requiring considerable test equipment and special tools should be conducted in the laboratory or shop. Minor repairs, generally classified as field repairs, can be done at the relay location. Always consult the manufacturer's relay instruction book before any repairs are made.

a. Field repairs. In most relays, contact and gasket replacement, case, cover, and some bearing repairs can be done at the relay panel. Often, a relay may have to be removed to get at the part needing repairs. Modern relays can be readily removed from the case thus facilitating field repairs. After repairs have been made, it may be necessary to make minor adjustments to ensure that the relay settings are correct. The manufacturer's relay instructions should be followed as to the procedure and test equipment required.

b. Shop repairs. Relays that require major repairs, such as overhauling electromagnets, tap blocks, bearings, shafts, or clutch and torque adjustments, should be worked on in a shop where adequate tools and testing facilities are provided. Before removal of any parts, the manufacturer's instructions should be checked for the proper procedures.

c. Overhauling. Exercise care in overhauling, as relays are easily damaged. There are a wide variety of relays with many complicated and delicate parts and it is impractical to list all the details that should be checked. Consult and follow the manufacturer's instruction and parts manual for the specific style of the relay being overhauled. Relays should be thoroughly cleaned at the time of overhaul. Test taps and tap blocks if coils are replaced. Where required repairs are extensive, return the relays to the factory.

d. Adjustments. After the overhaul,'various adjustments and alignments are required. Adjustment must be coordinated with other protective devices, as provided by a relay coordination analysis. The manufacturer's instruction manual should be referred to for the proper procedure. A few of the more important items that will require checking include shaft end play, contact gap, and torque and clutch adjustment. Depending on the degree of overhaul, some of these adjustments may not have to be changed; for instance, shaft end play should be

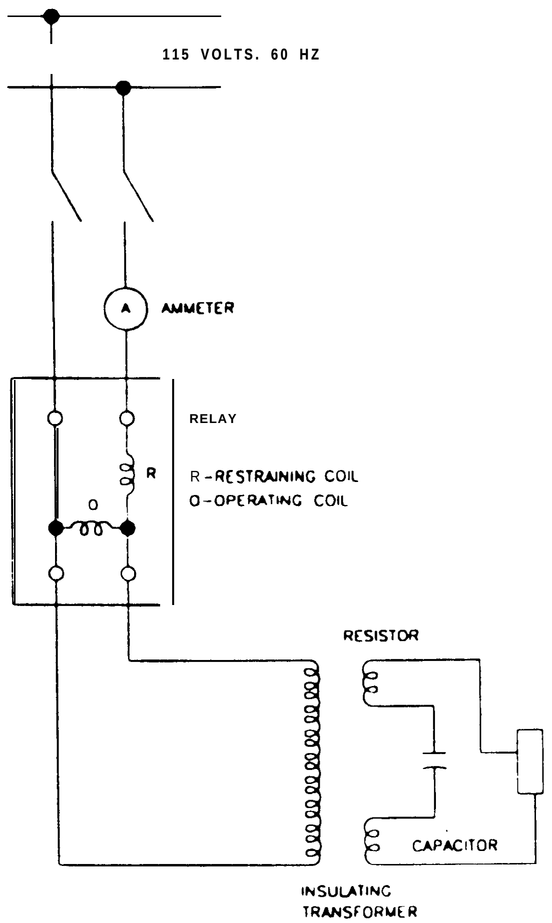

Figure 11-5. Typical test connection for a pilot wire relay

Table 11-l. Typical laboratory relay test equipment

Test equipment	Description
Variable voltage autotransformer	115 volt, 5 and 15-20 amperes
Multirange dc voltmeter.	3-15-150 volt, 5000 ohms
Multirange ac ammeter	0-2-5-l0-20-50-100-200 amperes
Multirange dc voltmeter.	0-3-7.5-30-75-150-300 volts
Multirange dc ammeter	0-5-20-50-amperes
Phase angle meter	5-10-30 amperes, 15-30-50-120-240-480 volts, 60 hertz
Auxiliary current transformers	1-5-10-25-50-62.5-125-250-500/5 amperes
Cycle counter or timer.	0-10 seconds, 120 volts
Phase shifter	three-phase, 500 watts
Multirange noninductive load resistor	0-100 amperes range
Three-phase sequence indicator.........................	110-550 volts, 25-60 hertz
Auxiliary relays, dc	125 volt

satisfactory, provided the shaft or bearings have not been disturbed. In any case, the manufacturer's directions should be followed.

e. Performance check. Upon completion of repair work, complete performance tests should be made on the relay, even though the work done may not appear to affect relay operation. It is possible that during repair, other adjustments or alignment of relay parts may have been changed or affected. After an overhaul, the tests made should not be less thorough than the relay's original acceptance tests.

Section II-CONTROLS

11-10. Control functions.

Controls are broadly defined as the methods and means of governing the performance of any electric apparatus, machine, or system, by sensing any need for a change and facilitating that change. In performing these duties, control circuits or systems may act to regulate, protect, indicate, open, close, or time an operation. Control devices execute control functions.

a. Control equipment. Some of the more common equipment controlled are switches, circuit breakers, contactors, lights, rheostats, timers, and valves. Control schemes use combinations of the following component parts to produce the desired operation: alarms, batteries, coils, fuses, relays, solenoids, timers, switches, and transformers. Other special electrical equipment may be used also.

(1) *Electromechanical controls.* Electromechanical controls are operated by magnets, thermal action, motors, or other mechanical or static actions.

(2) *Solid-state controls.* Solid-state controls perform similar functions to electromechanical controls, but their characteristics are affected to a much greater degree by ambient temperature changes and excessive electrical circuit parameters.

b. Power supply. Control equipment may be powered from storage batteries or from an ac source. Controls will only be as dependable as their operating input. The power supply must be as reliable as possible, so that control and protection of the equipment is not jeopardized. See chapter 14 for details of battery maintenance and repair.

c. Control lines. Pneumatic and electromagnetic controls are gradually being replaced by electronic loop controls, as systems are increasingly being incorporated into energy management control systems (EMCS) or supervisory control and data acquisition systems (SCADA). Sensors are used to provide units of information via conventional (hard) wiring to the field interface devices (FIDs). A sensor is installed as a component part of the electrical apparatus being controlled and must be maintained by electrical maintenance personnel. Control line components such as FIDs, data transmission links, the central processing unit (CPU) and its subcomponents are not electrical maintenance responsibilities. Communication, not electric, lines are used, such as telephone pairs; coaxial cable; radio, microwave or power line carrier signals; and fiber optics, sometimes as a part of a local area network (LAN).

11-11. Preventive maintenance and inspections of controls.

A well planned schedule of maintenance and inspections will pay large dividends in fewer interruptions and longer equipment life. More frequent inspections may be necessary for apparatus that receives hard service or is located in dirty, dusty, or damp locations. Only specially trained personnel should attempt to service and maintain control equipment.

a. Wiring diagrams and tools. Complete wiring diagrams are necessary to adequately service controls. Simplified schematic diagrams, showing all current and potential coils and contacts, are also very desirable for maintenance work. These diagrams expedite locating and correcting trouble. Keep wiring diagrams up-to-date and indicate any changes that have been made in the system subsequent to its installation. Proper tools and test equipment must be available for servicing special equipment. An adequately equipped laboratory or shop, with portable test apparatus, is necessary for major repairs.

b. Connections. Periodically, and after any wiring changes, connections and circuits should be completely checked for proper operation. Maintaining an installation free and clear of dirt, dust, grease, and other contaminants will help ensure proper operation. Loose connections may occur at times, and should be corrected as soon as possible to avoid serious damage to other equipment.

c. Contacts. Control equipment power contact surfaces are usually of silver, copper, weld-resistant alloys, or other electrically sensitive materials. Silver tips should never be filed or cleaned with abrasive materials. Crocus cloth is best for cleaning silver contacts. Copper and weld-resistant tips may be filed; however, care must be taken to ensure that only enough oxide is removed to attain good contact. The so-called electrically sensitive materials, including gold, platinum, and rhodium, are used for special applications where good electrical connection with low contact pressure is desired. The manufacturer's instructions should be followed for treating these contacts. Inspections and perhaps cleaning as often as monthly may be required for contacts which switch heavy currents frequently.

d. Magnet-operated devices. Magnet operated components such as relays, coils, solenoids, and brakes should be inspected periodically for dirt, heating, freedom of moving parts, corrosion, wear, noise, and general overall condition. Tests on some of these items may be necessary at times, particularly after a faulty operation. These tests will have to be conducted when the machine or equipment being controlled can be removed from service. Monthly inspection should be adequate. Annual testing of the insulation will detect defective wiring before the insulation breaks down.

e. Thermally-operated devices. Thermostats, thermal overload units, and temperature devices operate on the heating effect of electric current. Inspect units about once a month for dirt, excess heating, freedom of moving parts, corrosion, wear, and condition of the heating elements. As elements which normally operate only when an overload or trouble takes place in the equipment being controlled, they must be in good operating condition at all times.

f. Motor-operated devices. Motor-operated timers, thrusters, valves, and brakes are included in this category. Periodic inspections should be made for evidence of dirt, heating, corrosion, wear, noisy operation, and vibration. Such inspections should ensure correct voltage, freedom of moving parts, proper lubrication, adequate gaskets, and satisfactory condition of gearing. Cleanliness is particularly important in mechanical linkages. Trial operation of moving parts may be necessary to detect trouble. As this may necessitate temporary removal from service, actual operation tests if necessary should be coordinated with scheduled equipment outages. Monthly inspections should be satisfactory, but for extremely dirty locations more frequent inspections are desirable.

g. Mechanically-operated devices. Mechanically-operated devices include master, selector, knife, limit, speed, flow, float, and pressure switches; drum controllers; push buttons; and manual starters. Inspections of these parts for dirt, heating, corrosion, restriction of moving parts, contact and alignment wear, general condition, sealing, sludge, and lubrication are required. Each individual case must be studied on its own merits to determine if the seriousness of the condition justifies an interruption of operation for maintenance. In some cases, temporarily disconnecting the control circuit long enough for repairs may be possible. Inspections every 6 months should be satisfactory, but more frequent inspections may be necessary where contamination is severe.

h. Static accessories. Static accessories include resistors, rectifiers, capacitors, arc chutes, shunts, interlocks, transformers, fuses, wiring, and bus cables. Inspect for dirt, heating, corrosion, proper clearances, and loose connections. The urgency of any required corrective measures should be established in accordance with the seriousness of the condition. In general, inspections should be made every 6 months; however, more frequent inspections may be desirable where unusual conditions prevail.

i. Solid-state devices. Because of the nature of the parts used (resistors, reactors, capacitors, transformers, transistors, and integrated circuits), little maintenance is required. Inspection and testing are done at comparatively long time intervals. Transistors and integrated circuits are usually replaceable items and need little servicing. Many control parts are similar to those used in magnetic controls, such as cases, bases, terminals, wiring, and conduit devices. Standard magnetic control items, such as fuses, switches, contactors, overload devices, and some relays, may be used in conjunction with solid-state devices. The infrequent operation of controls used in starting and stopping operations may lead to special maintenance problems. Inspections every 6 months should be satisfactory, unless this period exceeds manufacturers' recommendations.

(1) *Characteristics.* Ambient temperatures, vibration, electrical noise, surge currents, and transient overvoltages, in excess of those specified by the manufacturer, can cause unacceptable affects. Always check that system characteristics do not exceed the requirements stated in the manufacturers' instructions.

(2) *Precautions.* Polarized devices connected incorrectly may malfunction and damage the equipment controlled. Though a solid-state device may have no applied control signal, there can be a small amount of current flow. Precautions are necessary to ensure proper circuit protection and personnel safety. Before working on the circuit or load, such devices should be disconnected from the power source to prevent energizing of an input device.

(3) *Testing.* Follow the manufacturer's procedures and recommendations. Do not use a low impedance voltage tester. Do not make high-voltage insulation tests or dielectric tests unless solid-state devices have been disconnected. Ohmmeters should only be used when and as recommended by the manufacturer. If testing equipment can not be grounded, special precautions should be taken. Also refer to NEMA ICS 1.1.

j. Test equipment. Commonly used test equipment includes multirange ac and dc ammeters and voltmeters, timers, ohmmeters, and auxiliary relays. Test leads, resistors, and tool kits are also required for servicing controls. A suitable shop should be available when major repairs are to be made. If solid-state equipment is to be checked, an oscilloscope or oscillograph and a high resistance voltmeter will be required.

k. Repair parts. Spare parts should be kept on hand, particularly if the equipment cannot be taken out of service for long periods of time. Parts should be stocked if they receive considerable wear or experience frequent replacement. A list of spare parts from the appropriate manufacturer can be used as a general guide for stocking. When broken or damaged parts are returned to the manufacturer, they should be accompanied with complete information regarding model number, nameplate data, duty cycle, service conditions, description of the failure, and probable reasons for the failure.

11-12. Troubleshooting controls.

In order to expedite repair work, it is important that the technician be thoroughly familiar with the equipment and the control operation. An elementary wiring diagram is most useful in maintenance or inspection work and should be available near the equipment. Portable testing instruments for checking continuity, resistance and adequacy of insulation, voltage, and current should also be available.

a. Solid-state devices. The list of possible troubles which can occur in solid-state control equipment is too length to be of value here. Instruction books prepared and furnished by equipment manufacturers usually contain troubleshooting guides, which should be used.

b. Electromagnetic devices. Table 11-2 lists some of the more common troubles (with their causes and remedies) encountered in general control equipment.

Table 11–2. Troubleshooting chart for general control equipment

Trouble	Cause	Course of action
CONTACTS:		
Contact chatter.	1. Low voltage or current	Check voltage and current.
	2. Poor contact in control pickup circuit	Improve the contact or use holding interlock.
	3. Excessive chattering after jogging..	Find out whether device is recommended for jogging service. If not, caution operator.
	4. Broken pole shader or parts.	Replace defective part.
	5. Contactor slams, thus opening interlock in coil circuit.	Increase wipe and pressure on interlock.

Table 11-2. Troubleshooting chart for general control equipment (continued)

Trouble	Cause	Course of action
Overheating of contact tips	1. Copper oxide on contact tips or tips in poor condition	Install silver-faced tips. If copper tips, file with a fine file or replace tips. **CAUTION:** Excess filing wears out the tips. Never file silver-faced tips.
	2. Carrying load continuously for a long time.	Install silver-faced tips or clean tips. Check application.
	3. High inductive loads.....................	Install silver-faced tips.
	4. Sustained overload.	Reduce current or install a larger device.
	5. Low tip pressure.	Clean, adjust, check springs.
	6. Loose connection.	Clean and tighten. Check voltage drop across tips.
Short circuit currents on contacts .	1. Feeder fuses too large	Eliminate short circuits or use smaller fuses in feeder.
Short tip life.	1. Interrupting high currents. Tip life varies approximately inversely as the square of the current interrupted.........................	Install special tips designed to withstand arcing better than copper. (There are cases where these cannot be used because of their high resistance and lower rating.) For jogging service, install larger device designed for jogging service.
	2. Excessive filing or dressing..	Do not file silver tips. The rough spots will not hurt them.
	3. Oil immersed device is a misapplication. **(NOTE:** Oil immersed tips burn away from 20 to 40 times as fast as similar tips breaking the same current in air.).	Change to air break device if oil is not essential.
	4. Mechanical rebound on dropout, causing tips to touch.	Reduce rebound, or report trouble to manufacturer.
Weak tip pressure	1. Defective part.	Replace part.
	2. Wear allowance gone..	Replace and adjust.
	3. Poor tip adjustment..	Adjust gap and wipe.
	4. Low voltage that prevents magnet sealing	Correct voltage condition (possible line regulation).
Welding or freezing	1. Abnormal inrush of currents of more or less than 10 times continuous rating. This will vary, depending on the type of device....	Reduce currents. Substitute special nonweld tips. Install larger device. Install copper tips. **CAUTION:** The possibility of overheating copper tips should be considered.
	2. Rapid jogging.	Install copper tips if otherwise suitable
COILS:		
Coil failure	1. Loose connection.	Tighten connections.
	2. Moisture, corrosive atmosphere.	Relocate coils or use special resistant coils. Dry out coils.
Open circuit not roasted.	1. Mechanical damage..	Do not handle coils by the leads.
	2. Excess vibration or shock; coil movement causing insulation failure or broken wire.	Check manufacturer.
Overheated, roasted.	1. Overvoltage or high ambient.	Check application and circuit.
	2. Wrong coil, short time rated coil energized too long..................................	Check manufacturer.
	3. Shorted turns, caused by mechanical damage, corrosion, or conducting dust..	Replace coil and correct conditions if practical to do so.
	4. Too frequent operation (very rapid jogging of ac coils).	Check application.
	5. Under-voltage, failure of magnet to seal in.	Check circuit interlock.
Series coils overheated (Includes blowout coils).	1. Overloaded..	Install larger coil, or reduce current.
	2. High ambient.	Relocate, or reduce temperature.
	3. Loose connection, corrosion, oxidation on connection surfaces..	If connection is hot, clean before tightening.
Flexible shunt failure	1. Improper installation.	See manufacturer's instructions.
	2. Too many operations.....................	Replace shunt.
	3. Worn out mechanically.	Replace shunt.
	4. Corrosive atmosphere or moisture.	Replace shunt and correct condition.
	5. Burned by arcing; oxidized connection.....	Check application and system voltage.

Table 11-2. Doubleshooting chart for general control equipment (continued)

Trouble	Cause	Course of action
MAGNETS AND OTHER MECHANICAL PARTS:		
Worn or broken parts	1. Contacts slam in caused by: overvoltage, underload, wrong coil. Chattering caused by: broken pole shader or poor contact in control circuit. Heavy duty cycle. Too much jogging. Abrasive dirt, mechanical abuse.	Replace part and correct cause of damage. **NOTE:** The mechanical life should be measured in number of operations.
Noisy magnet.	1. Broken pole shader, magnet faces not true (result of wear or mounting strains).	Replace. (For locations where the ac hum is objectionable, use dc magnets. Hum can be reduced by mounting on rubber or springs.)
	2. Dirt or rust on magnet faces.	Clean magnet.
	3. Low voltage.	Check system voltage.
Broken pole shader	1. Contacts slam in caused by: overvoltage, magnet underloaded, weak tip pressure, wrong coil.	Replace and correct the cause.
SLIDING CONTACTS:		
Abrasion roughening of contacts	1. Lack of care and lubrication; very heavy service; arcing; oxidation; abrasive dirt.	Sliding contacts usually require lubrication. (Use lubricant recommended by manufacturer.) Special alloy contacts should be specified for extra heavy service.
Arc	1. Abnormal interrupting duty such as inductive loads, excess vibration, or shock.	Check application. NOTE: On severe-duty applications, arc chutes wear out and must be replaced periodically.
	2. Moisture	Eliminate presence of moisture. Keep several chutes on hand for replacement.
	3. Improper assembly.	See manufacturer's instruction sheet.
	4. Rough handling.	Replace.
Drum switches, rheostats, knife switches overheating.	1. Overcurrent; low contact pressure; oxidation; high ambient; rough contacts.	For very heavy service, use special alloy contacts. Lubricate periodically as manufacturer recommends.
Insulation failure	1. Overvoltage, voltage transients, high induced voltages, moisture.	Correct system voltage and conditions. Use discharge resistors where needed.
	2. Mechanical damage.	Replace damaged parts. Correct condition.
	3. Moisture, dirt and fumes, overheating (carbonizing).	Keep controls clean and dry. Get special coil for application.
Failure to pick up.	1. Low voltage on coil.	Check system voltage.
	2. Coil open, wiring of coil or shortened turns	Replace.
	3. Wrong coil.	Check manufacturer for recommendations.
	4. Excessive magnet gap, magnet overloaded.	Check instruction sheet and adjust.
Failure to drop out magnet-operated device	1. Mechanical binding.	Check instruction sheet, and adjust.
	2. Gum or dirt on magnet faces.	Clean.
	3. Worn bearings.	Replace the part.
	4. Nonmagnetic gap in magnetic circuit destroyed	Replace magnet.
	5. Contact tip welded.	Use other contact material.
	6. Voltage not removed.	Check coil voltage.
	7. Not enough mechanical load on magnet, improper adjustment.	Check instruction sheet, and adjust.
OVERLOAD RELAYS:		
Magnet-operated instantaneous-type, high trip or low trip.	1. Wrong coil.	Install coil with correct rating.
	2. Shorted turns (on high trip).	Test coil and replace if found defective.
	3. Mechanical binding; dirt, corrosion, etc.	Clean parts with suitable solvent.
	4. Assembled wrong.	See manufacturer's instruction sheet.
	5. Wrong calibration.	Refer to manufacturer.
Magnet-operated inverse-time type, slow type.	1. Fluid too viscous, vent too small, or temperature too low.	Change fluid and open vent slightly, or regulate temperature.
	2. Mechanical binding; dirt corrosion, etc.	Clean parts with suitable solvent.
	3. Worn parts.	Replace and adjust.
Fast trip	1. Worn or broken parts.	Replace.

Table 11-2. Troubleshooting chart for general control equipment (continued)

Trouble	Cause	Course of action
	2. Same as above, except fluid dry or too light. Vent too large or temperature too high.	Use heavier fluid or close vent slightly or regulate temperature. Dashpots should be cleaned periodically and refilled with new oil.
Thermal type.	1. Wrong size of heater.	Check rating with manufacturer's instruction sheet.
Failure to trip causing motor burnout	1. Mechanical binding; dirt, corrosion, etc..	Clean and adjust relay.
	2. Relay damaged by short circuit.	Replace relay.
	3. Motor and relay in different ambient temperatures	Install motor and control near to each other, or make temperature uniform for both. Use ambient-compensated relay.
Trips at too low temperature.	1. Wrong heater..	Check rating with manufacturer's instruction sheet.
	2. Assembled wrong..	See instruction sheet.
	3. Relay in high ambient temperature.	Install controls closer to each other, or make temperature uniform. Use ambient-compensated relay.
	4. Wrong calibration.	Consult manufacturer.
Failure to reset.	1. Broken mechanism; worn parts; corrosion, dirt	Replace broken parts, clean, and adjust.
Burning or welding of control contacts and shunts.	1. Short circuits on control circuit with too large protecting fuses	In general, use fuses of not over 10 ampere rating.
	2. Severe vibration	Remount control.
	3. Dirt, corrosion.	Clean and adjust.
	4. Misapplication, current too high.	Reduce current or get manufacturer's recommendations.
TIMING RELAYS:		
Mechanical escapement type, mechanical wear or broken parts	1. Abrasive dirt.	Clean and replace worn parts.
	2. Wrong application.	Get manufacturer's recommendations.
	3. Very heavy service cycle	Get manufacturer's recommendations.
Jamming or sticking	1. Dirt; corrosion; moisture; lack of lubrication; worn or broken parts.	Clean and lubricate moving parts; replace worn or broken parts. Correct condition.
Decay of flux type, too short time .	1. Dirtinairgap..	Clean.
	2. Shim too thick.	Replace with thinner shim.
	3. Excess spring and tip pressure.	See instruction book.
	4. Misalignment.	Correct alignment and remedy with cause.
Decay of flux type, too long time ..	1. Shim worn	Replace with heavier shim.
	2. Weak spring and contact pressure. Gum or dirt on magnet faces, or mechanical binding..	See instruction book. Clean and adjust.
Magnet-operated capacitor type, too short time	1. Dirt or gum in air gaps.	Clean.
	2 High spring and contact pressure..	See instruction book.
Magnet-operated capacitor type, too long time	1 Mechanical binding or sticking.	Clean and adjust.
	2 Worn shim	Replace.
	3 Weak spring and tip pressure.	See instruction book.
	4 Too much capacitance or resistance.	Chck manufacturer.
Motor-operated type, failure to time out.	1. Worn or broken parts.	Replace parts and adjust them.
	2. Corrosion, dirt..	Clean.
	3. Motor damaged.	Check condition of motor electrically and mechanically.
	4. No voltage on motor.	Check circuit.
Failure to reset	1. Worn or broken parts; corrosion, dirt.	Replace parts and adjust.
BRAKES:		
Magnet-operated or thrustor-operated, worn *or* broken parts	1. See magnets and other mechanical parts.	
	2. Heavy duty cycle, high inertia loads, excess temperature, rough surface on wheels, misapplication.	Check application. A larger or different type brake may be needed.
Failure to hold load	1. Worn parts, out of adjustment, wrong friction material used for replacement.	Replace worn parts.

Table 11-2. Troubleshooting chart for general control equipment (continued)

Trouble	Cause	Course of action
	2. Grease or oil on brake wheel.	Remove grease or oil.
Failure to set.	1. Out of adjustment; worn parts, mechanical binding.	Replace worn parts and adjust them.
	2. Coil not de-energized.	Examine brake and check circuit to make sure current is cut off.
Failure to release	1. Out of adjustment.	See manufacturer's instructions.
	2. Coil not energized; low voltage or current.	Check connections.
	3. Wrong coil.	Check with manufacturer as to correct coil.
	4. Shorted turns or coil open.	See manufacturer's instructions.
	5. Coil not energized; low voltage or current.	Check to see if coil is getting correct voltage or current.
	6. Open coil or shorted turns..	Replace coil.
VALVES:		
Electrically-operated, solenoid, thrustor, or motor-operated, leaks and mechanical failure	1. Worn valve seal.	Replace seal or valve.
	2. Abrasive matter in fluid..	Check application; use strainer ahead of each valve.
	3. Corrosion	Remove corrosive elements from fluid, or get manufacturer's recommendations.
Noise	1. Same as for noisy magnet.	See noisy magnet.
	2. Water hammer.	Install surge tank.
THRUSTORS:		
Failure to more load	1. Worn parts.	Replace worn parts.
	2. No voltage on motor.	Check circuit and connections.
	3. Misapplication.	Get manufacturer's recommendations.
THERMOSTATS:		
Bulb and bellows type, with expanding fluid, bellows distorted	1. Mechanical binding.	Clean and adjust.
	2. Temperature too far above normal.	Replace bellows.
Bulb distorted	1. Liquid frozen in capillary tube, or tube stopped up..	Replace bulb and bellows assembly.
RESISTORS:		
Insulation failure	1. See insulation failure.	See insulation failure.
Overheating.	1. Rating too low.	Install larger resistor.
	2. Running on starting resistor..	Check the timer to make sure it operates.
	3. Restricted ventilation.	Relocate.
Open circuit.	1. Burned out from overheating.	Replace resistor and see above.
	2. Corrosion, moisture, acid fumes, ...	Relocate or correct atmospheric conditions.
	3. Mechanical damage.	Replace worn or broken parts.
RECTIFIERS-DIODES:		
Dry type, overheating	1. Overvoltage	Correct system voltage.
	2. Overcurrent, intermittent-rated unit left on continously	Check operation of circuit and application.
	3. High ambient.	Relocate unit or correct condition.
	4. Misapplication.	Get manufacturer's recommendation.
Failure burnout or breakdown ...	1. Overheating, corrosive atmosphere, overvoltage, mechanical damage	Same as for overheating.
CAPACITORS:		
Breakdown or failure of dielectric	1. Overvoltage.	Check system voltage.
	2. Voltage surges caused by switching or lightning.	Install protective equipment.
	3. Some types not usable on ac..	Check applications.
	4. Moisture, corrosion, or high temperature. .	Correct condition, or install special unit.
	5. Continuous voltage on intermittent-rated unit.	Install proper unit.
	6. Mechanical damage..	Replace capacitor.
	7. Wrong polarity on dc unit.	Replace capacitor and reconnect, changing polarity.
FUSES:		
Premature blowing.	1. Fuse too small..	Check application.

Table 11-2. Troubleshooting chart for general control equipment (continued)

Trouble	Cause	Course of action
	2. Heating at ferrle contacts, corrosion or oxidation of ferrules and clips..	Keep ferrules and clips clean. Use plated clips and ferrules; replace annealed clips.
	3. Weak contact pressure.	Provide adequate pressure.
Too slow blowing.	1. Wrong size of fuse for application.	Check application.
TRANSFORMERS:		
Overheating.	1. Overcurrent or overvoltage.	Check load on transformer and system voltage.
	2. Intermittent-rated unti left on continuously.	Failure of other devices to operate properly.
	3. High ambient.	Relocate transformer or reduce load.
	4. Shorted turns.	Replace coil.
Insulation failure	1. See insulation failure.	See insulation failure.
MASTER, SELECTOR, LIMIT, SPEED, FLOAT, FLOW, PRESSURE, KNIFE, AND DRUM SWITCHES; PUSH BUTTONS. MANUAL CONTACORS, RHEOSTATS:	These causes are similar to those listed under contacts, mechanical parts, and insulation. ..	See contacts, mechanical parts, and insulation failure.
MANUAL STARTERS:	These causes are similar to those listed under contacts, sliding contacts, mechanical parts, insulation failure, and thermal overload relays.	See contacts, sliding contacts, mechanical parts, insulation failure, and thermal overload relays.
MOTOR STARTER CIRCUIT BREAKERS:		
Premature tripping	1. Setting too low.	Reset or increase trip setting.
	2. Repetitive closing and jogging.	Check load and current peaks against setting.
	3. Undervoltage device and control circuit and auxiliary pilot devices affected by operating circuit.	Check circuits.
	4. Incorrectrating.	Replace circuit breaker.
Failure to latch in or open and reset......................... ...	1 Incorrect adjustment.....................	See circuit breakers instructions. Check and adjust parts.
	2. Worn parts.............................	Replace parts.
	3. Excessive currents causing contact wear...	Replace circuit breaker.
	4. Fault in remote control circuit............	Check circuits.
	5. Door mechanism out of adjustment.	Readjust.
	6. Trip element or mechanism damaged.	Replace parts.
	7. Corrosion or dirt.........................	Clean.
	8. Arc chutes damaged.	Replace parts.
Short contact life	1. Corrosion.	Check starting current, reduce duty cycle.
	2. High currents and frequent operation causing burning.	Check starting current, reduce duty cycle.
	3. Misapplication.	Refer to manufacturer.
	4. Excessive filing and dressing.	Do not file contacts.
Welding of contacts...............	1. High inrush currents during motor starting.......................................	Reduce currents.
	2. Rapid jogging.	Use suitable contactor.
	3. Incomplete manual closure.	Frequent inspection.
	4. Inadequate maintenance for renewal of contacts.	Renew contacts.